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AN ESTIMATE OF SEDIMENT MOVEMENT IN NORTH DITCH, WAUKEGAN, ILLINOIS

By

Allen W. Noehre and Julia B. Graf

Administrative Report

Prepared in cooperation with the
U.S. Environmental Protection Agency

1980

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CONVERSION FACTORS

Multiply Inch-pound unit	By	To obtain SI (metric) unit
mile (mi)	1.609	kilometer (km).
foot (ft)	0.3048	meter (m).
inch (in)	25.40	millimeter (mm).
foot per second (ft/s)	0.3048	meter per second (m/s).
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s).
pound (lb)	0.4536	kilogram (kg).
pound per cubic foot (lb/ft^3)	0.01602	grams per cubic centimeter (g/cm^3).
pound per hour (lb/h)	0.4536	kilogram per hour (kg/h).

Temperature

degrees Fahrenheit (°F)	-32 x 0.555	degrees Celsius (°C).

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ABSTRACT

Stage-discharge and sediment-discharge to stream-discharge relations have been developed for North Ditch, Waukegan, Ill., a small tributary to Lake Michigan. Indirect methods were used to obtain a stream-discharge rating curve, and discharge and stage measurements were used to adjust that relation. Transport curves for discharge of both measured sediment and bed material were developed from measured sediment concentrations and by calculation from three indirect methods. The stream- and sediment-discharge relations were used with stage record to estimate daily sediment load in the ditch for the study period March 13 to September 30, 1979. Maximum daily sediment load during that period, as estimated from the measured-sediment transport curve, was 450 lb. Mean daily sediment load for the 202-day period was 25 lb; the sediment load for the study period was 5,100 lb. Peak stream discharges estimated by empirical equations for floods of 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals were used with a bed material transport curve to estimate sediment discharge for these floods. Total bed material discharge for the same floods is estimated to be 220 lb/h for the 2-year flood peak and 1,600 lb/h for the 100-year flood peak.

INTRODUCTION

A short-term study of the flow and sediment-transport characteristics of North Ditch, a small tributary to Lake Michigan, was undertaken because of a need for the determination of the rate of movement of streambed materials into Lake Michigan. North Ditch drains property belonging to the Outboard Marine Corporation and the North Shore Sanitary District at Waukegan, Ill. (fig. 1). Data collection necessary for the study included bed-material samples, channel geometry and slope data, continuous precipitation and stage measurements, discharge measurements, and sediment-concentration information. These data were collected from March 13 through September 30, 1979.

Channel characteristics, stage record, and stream-discharge measurements were used to develop a stage-discharge relation for the ditch and to estimate hourly and mean daily discharges for periods of flow. Corresponding daily loads of sediment were estimated using a transport curve computed from measured sediment concentrations. Flood-peak stream and bed-material discharges were also estimated.

The 0.11 mi^2 drainage area includes plant buildings, parking lots, roads, railroads, and an expressway, for a total of about 40 percent impervious surface. The area between gages 4 and 5 (fig. 1) is wooded and grassy and it serves as a disposal site for urban debris. Downstream, cattails

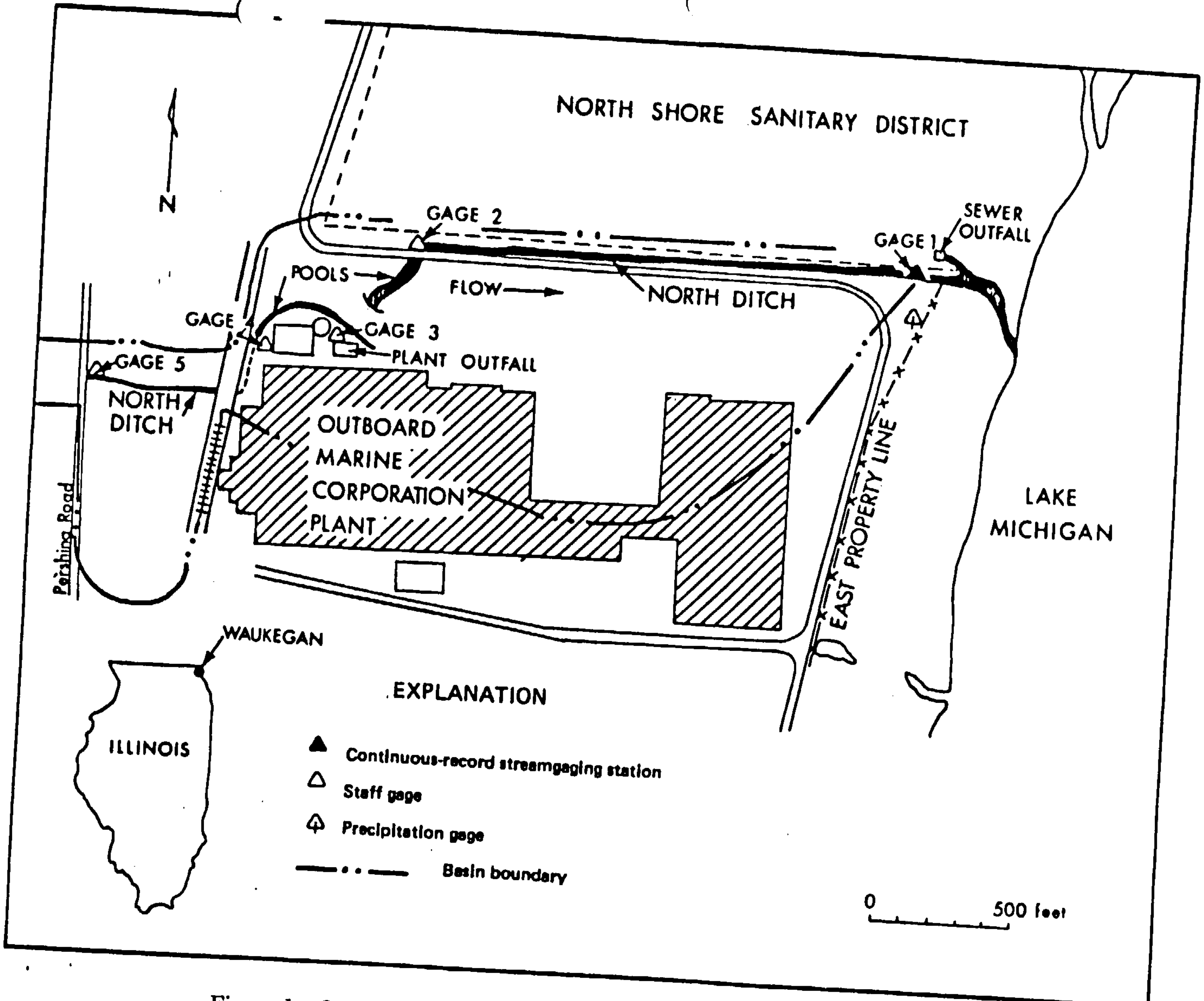

Figure 1.—Location of study area and hydrologic monitoring stations.

and other vegetation grow along the ditch. The ditch drains an area of land fill which is composed of sandy material (Willman, 1971). The ditch itself is small, 3 to 5 feet deep and 20 to 40 feet wide across the top and is unlined except for a steel retaining wall which makes up much of the north bank between gages 1 and 2. A channel profile (fig. 2) shows that the steeper upper reach, between gages 4 and 5, is separated from the lower reach by three culverts and two pools.

Streambed material is composed of sand with some gravel; organic debris and finer sediments are found in the pools. Because of the large impervious surface area and the permeability of much of the remaining area, it is believed that a large proportion of the sediment load of the stream at gage 1 is derived from the channel itself.

The work was performed in cooperation with the U.S. Environmental Protection Agency whose personnel collected some of the sediment samples and analyzed sediment concentration for those samples.

SURFACE WATER RUNOFF

Field Data Collected

A stream-stage recorder gage (No. 1), four staff gages (Nos. 2-5), and a precipitation recorder were installed along a 3,329-foot reach of North Ditch from gage 1 to Pershing Road (figs. 1, 2). Figure 3 illustrates daily precipitation, stage, and mean discharge for the study period at gage 1 (gaps in stage record due to recorder malfunction). Elevation and cross-sectional geometry at 13 locations were obtained by level survey; roughness values (Manning's n) were selected during the survey.

Stream discharge was measured at gage 1 during several storm and low flow periods. Maximum discharge measured during the study at gage 1 was 5.3 ft^3/s. In addition, discharge measurements, gage heights, and some maximum stages were obtained at gages 2 through 5.

Stage-discharge Relation

Due to the short study period and lack of available data, indirect methods were used to develop the stage-discharge relation (rating curve). Field data were used to verify the computed relation in the range of the discharge measurements. Water-surface elevations (stage) were computed by the step-backwater computer program (Shearman, 1976) which is based on Chow's step method (1964). That method uses the energy equation with Manning's formula to estimate energy losses between consecutive cross sections. Required computer input data include discharge, stage, cross-section geometry, and Manning's n values.

Input values of discharge at gage 1 were estimated using empirical equations developed by Allen and Bejcek (1979) from multiple regression analyses of regional data from gaged sites in northern Illinois:

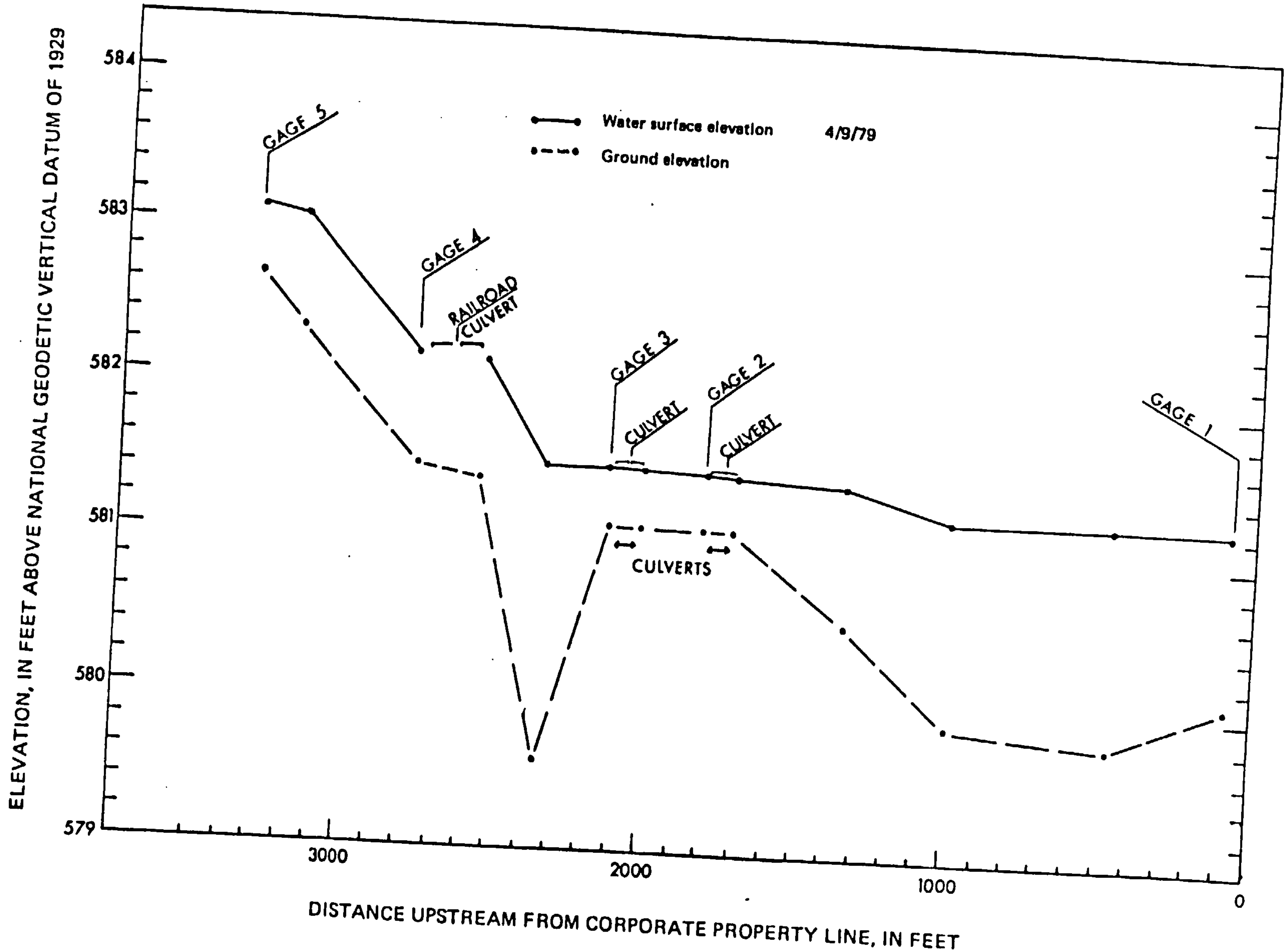

Figure 2.–Profile of North Ditch.

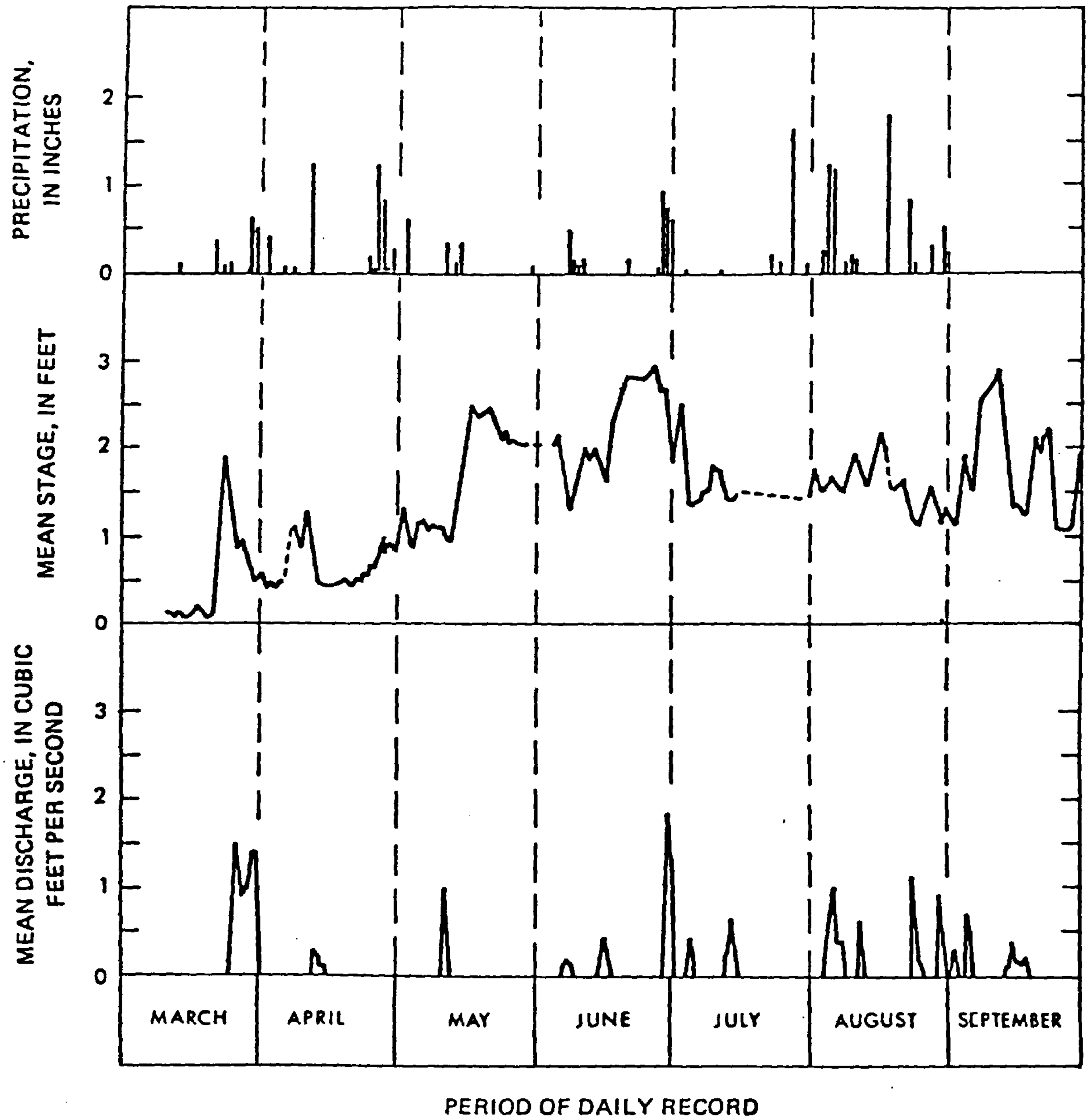

Figure 3.—Daily values of precipitation, mean stage, and mean discharge for the study period at gage 1.

$$Q_2 = 14.7\ A^{0.698}\ S^{0.241}\ If^{0.313}$$

$$Q_5 = 23.8\ A^{0.682}\ S^{0.284}\ If^{0.255}$$

$$Q_{10} = 29.8\ A^{0.675}\ S^{0.305}\ If^{0.228}$$

$$Q_{25} = 37.2\ A^{0.668}\ S^{0.325}\ If^{0.202}$$

$$Q_{50} = 42.7\ A^{0.664}\ S^{0.338}\ If^{0.186}$$

$$Q_{100} = 48.0\ A^{0.660}\ S^{0.349}\ If^{0.172}$$

where Q is stream discharge and the numbered subscript denotes the flood recurrence interval, A is drainage area, S is main channel slope, and If is percent imperviousness. The North Ditch drainage area, slope, and percent imperviousness were 0.11 mi^2, 6.29 ft/mi, and 40 percent, respectively.

Starting water-surface elevations at gage 1 were developed by the slope-conveyance method (Dalrymple and Benson, 1967) which makes use of Manning's equation. The energy slope used in Manning's equation was assumed to be equal to the general slope of the ditch.

Cross-section geometry and Manning's n, additional input values, were determined from field surveys. The range in Manning's n along the ditch was from 0.030 to 0.055 for the main channel with no overbank flow.

A culvert rating computer program based on methods described by Bodhaine (1968) was used to obtain a stage-discharge relation at gages 2, 3, and 4. Program input consists of approach section and culvert geometry, roadway elevation, and roughness coefficients. The culvert rating program calculates discharge from the continuity and energy equations. Discharge measurements made at gages 2, 3, and 4 were used to define the low end of the rating curve at each culvert. The stage-discharge relations at these gages were used to verify or to calibrate the stage computed by the step-backwater method.

Stage was not a reliable indicator of flow at gage 1. A barrier sand bar, built to various heights by wave action along the west shoreline of Lake Michigan (Visocky, 1977), often blocked flow from a sewage-plant outfall downstream from gage 1 and direct wave action from Lake Michigan were all observed to cause backwater in North Ditch and thus affect the stage-discharge relation during the study period. The barrier bar was breached and eroded during periods of rainfall when the water surface rose in the ditch causing the bar to become unstable.

The described backwater conditions caused the stage-discharge relation for gage 1 to shift to a lower discharge for any given stage. During those periods flow conditions were defined by use of a discharge measurement and the highest and lowest recorded elevation before and after the breaching of the barrier bar. Flow into Lake Michigan was observed on days during rapid drops in recorded stage at gage 1.

Hourly discharges were computed using the recorded stage with the rating curve. The hourly discharges were then averaged to determine mean daily discharges (fig. 3). Discharge could not be computed for 25 other periods because discharge measurements were not available to define the changing control conditions. During these periods and the periods of missing stage record, 2.81 inches of rainfall occurred or 14 percent of the total precipitation recorded during the study.

SEDIMENT MOVEMENT

Bed material of North Ditch was described, and initial estimates of sediment discharge were presented in a progress report (Graf, 1979). The three bed-material discharge relations presented in the progress report were calculated using indirect methods with measured bed slope, grain-size distribution of bed material, and an assumed water temperature. In this report, data from sediment concentration samples collected between March 13 and September 30, 1979, are presented, and a transport curve derived from those data is compared to the bed material transport curves given in the progress report.

Sediment Concentration Measurements

Samples for determination of sediment concentration were collected at gage 1 throughout two storm runoff periods (March 30 and April 11-12) and once during each of three miscellaneous periods of flow. The samples were collected using the equal width increment (EWI) method (Guy and Norman, 1970) which yields a representative sample of sediment carried above a level 0.3 ft from the streambed. Stream discharges during the two runoff periods were determined from staff gage readings made at the time of sampling, whereas measurements of stream discharge were made at the time of sediment sampling for the three miscellaneous samples.

The variation of sediment concentration and stream discharge with time for March 30 (fig. 4) is typical of the response of small streams with low base flows to a high intensity rainfall. The data for April 11-12 (fig. 4) show a situation which may be more typical for this ditch. During that period, streamflow at gage 1 was affected by strong onshore (upstream) winds which created waves and at times caused backwater conditions in the ditch.

Sediment Discharge Relations

Measured sediment discharge at gage 1 was computed for each sediment concentration sample and plotted against its corresponding stream discharge (fig. 5). A straight line fitted to the data using the least squares technique for regression of logarithms of the data is also shown. For comparison, the bed material transport relations calculated in the progress report have been replotted on figure 6 with the regression line.

Comparison of sediment discharges estimated from each of the four transport curves (fig. 6) reveals that the method of Graf and Acaroglu (1968) significantly overestimates sediment discharge through the ditch. The difference between the measured-sediment discharge data and the estimates

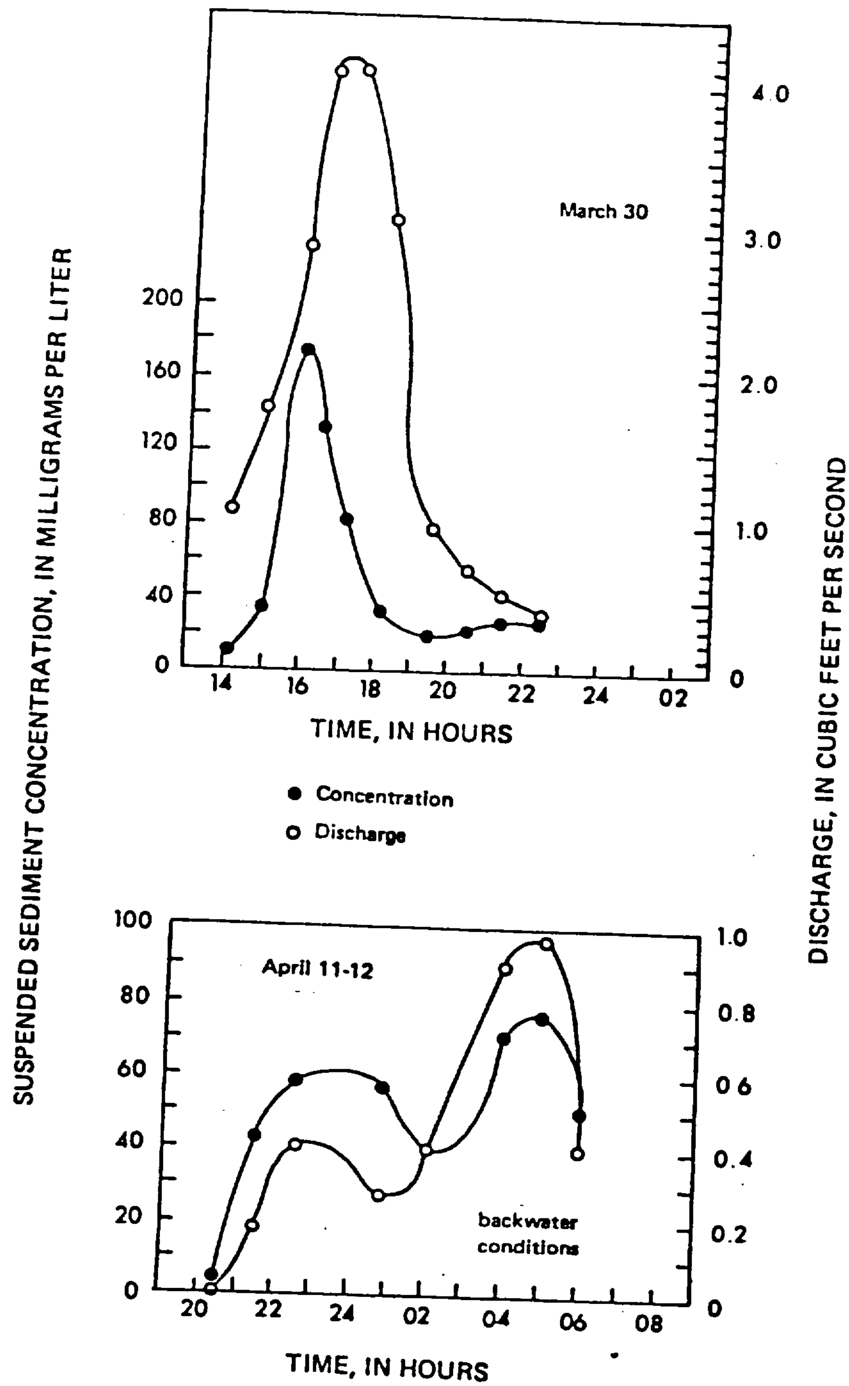

Figure 4.—Sediment concentration and stream discharge at gage 1 during two runoff periods.

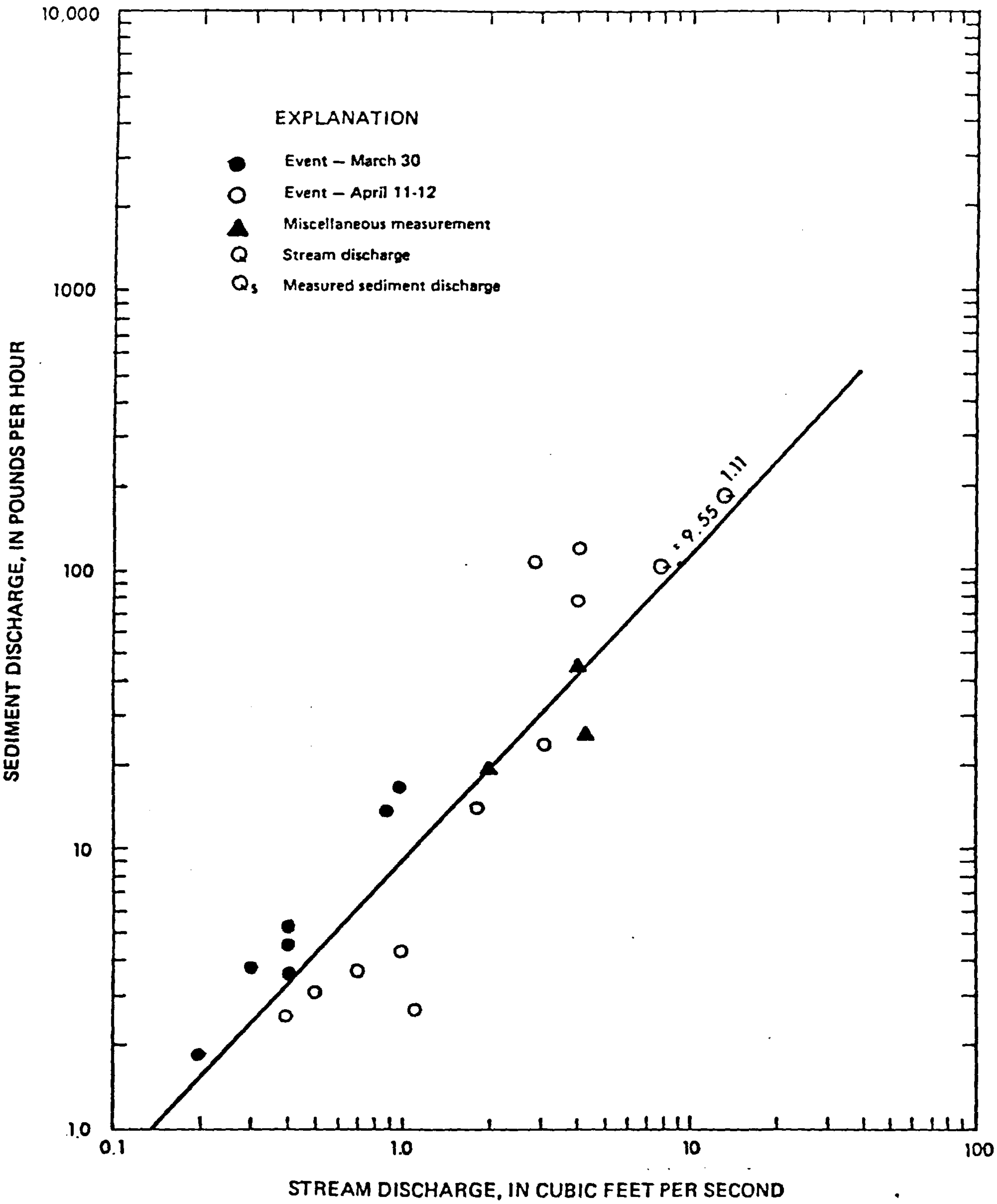

Figure 5.—Measured sediment discharge data and calculated regression line for North Ditch.

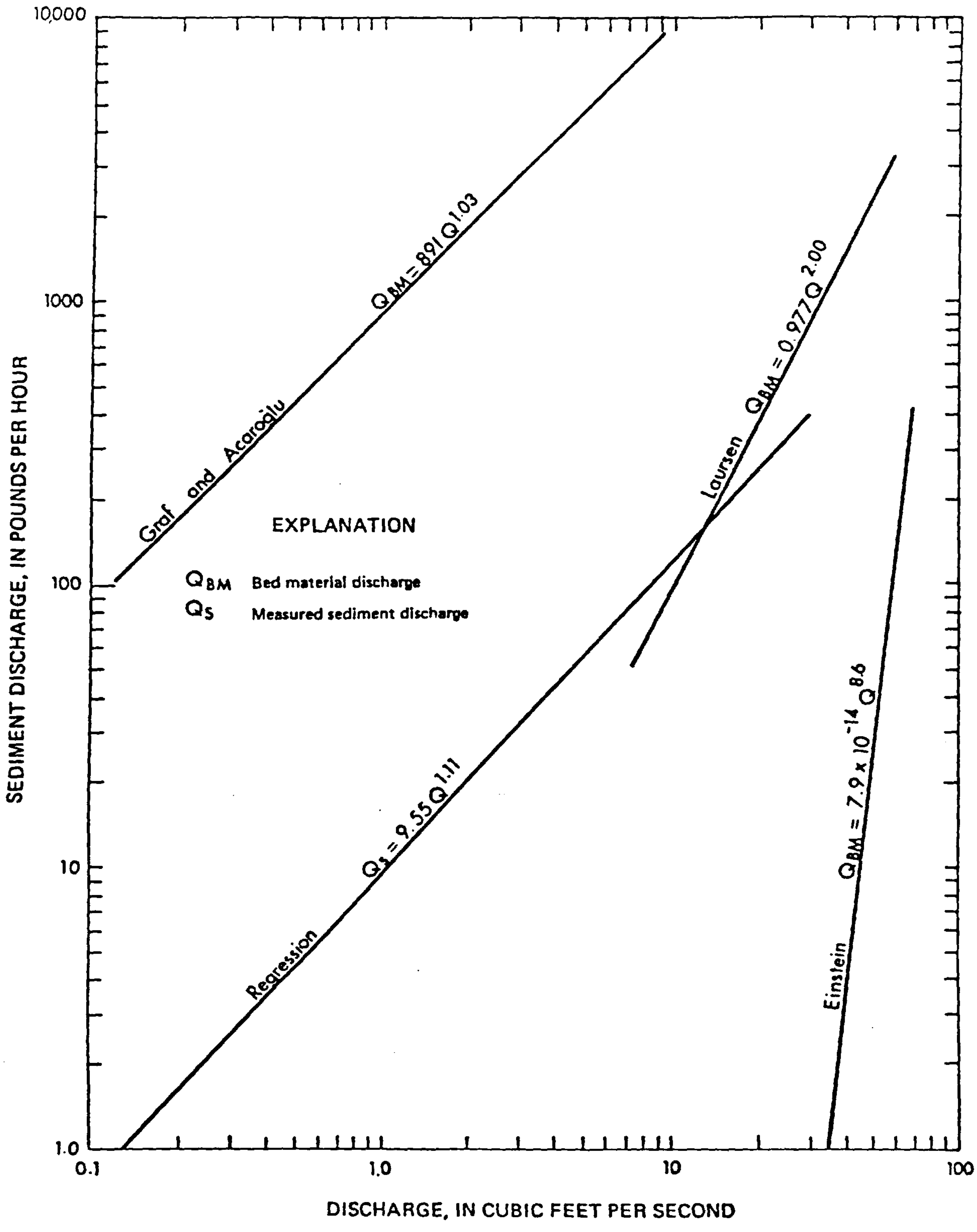

Figure 6.—Predicitive equations and transport curves for sediment discharge in North Ditch.

of bed material discharge by the Graf and Acaroglu method is assumed too large to be caused only by the unmeasured-sediment discharge, which is that portion carried between the bed surface and the lower limit of the suspended-sediment samples – 0.3 ft above the bed. Einstein's (1950) indirect method estimates bed material discharge orders of magnitude lower than any of the measured-sediment data over the entire discharge range.

The regression equation calculated for the measured-sediment data compares most closely with estimates made by Laursen's (1958) method. At low stream discharges, measured-sediment discharges are higher than those estimated with the Laursen method. The difference may be caused by the inclusion of silt and clay sized sediment in sediment samples. That very fine fraction is not accounted for in bed material transport calculations. At discharges higher than about 13 ft^3/s the Laursen method estimates greater sediment discharge than does the regression line. The difference between the two estimates (15 percent at a discharge of 15 ft^3/s and 66 percent at a discharge of 40 ft^3/s) is of the order of magnitude that can be expected for the difference between bed material discharge and measured-sediment discharge. Therefore, at discharges between 13 and 40 ft^3/s, the Laursen equation probably gives better estimates of the amount of sediment in transport than does the regression line.

A transport curve which is a composite of the lower section of the regression line and the upper portion of the transport curve calculated by Laursen's indirect method is given in figure 7. That curve can be used to estimate sediment discharge over the range of stream discharge expected in the ditch. Neither portion of the composite curve gives total sediment discharge. The lower section does not include the unmeasured-sediment discharge, and the upper does not include the silt and clay sized sediment that is considered not to be bed material. Because the highest discharge measured during the study period was about 5 ft^3/s, no verification of the upper portion of the transport curve was possible.

Flood peak discharges for six recurrence intervals, estimated from equations by Allen and Bejcek (1979), were used to estimate sediment discharge at gage 1 (table 1). Because all of the estimated discharges are above 13 ft^3/s, the transport curve obtained by Laursen's method was used to estimate sediment discharge.

Table 1.–Sediment discharges at gage 1 for flood peak stream discharges

Flood recurrence interval (year)	Estimated peak discharge (ft^3/s)	Sediment discharge (lb/h)
2	16	250
5	23	520
10	27	710
25	33	1,100
50	36	1,300
100	40	1,600

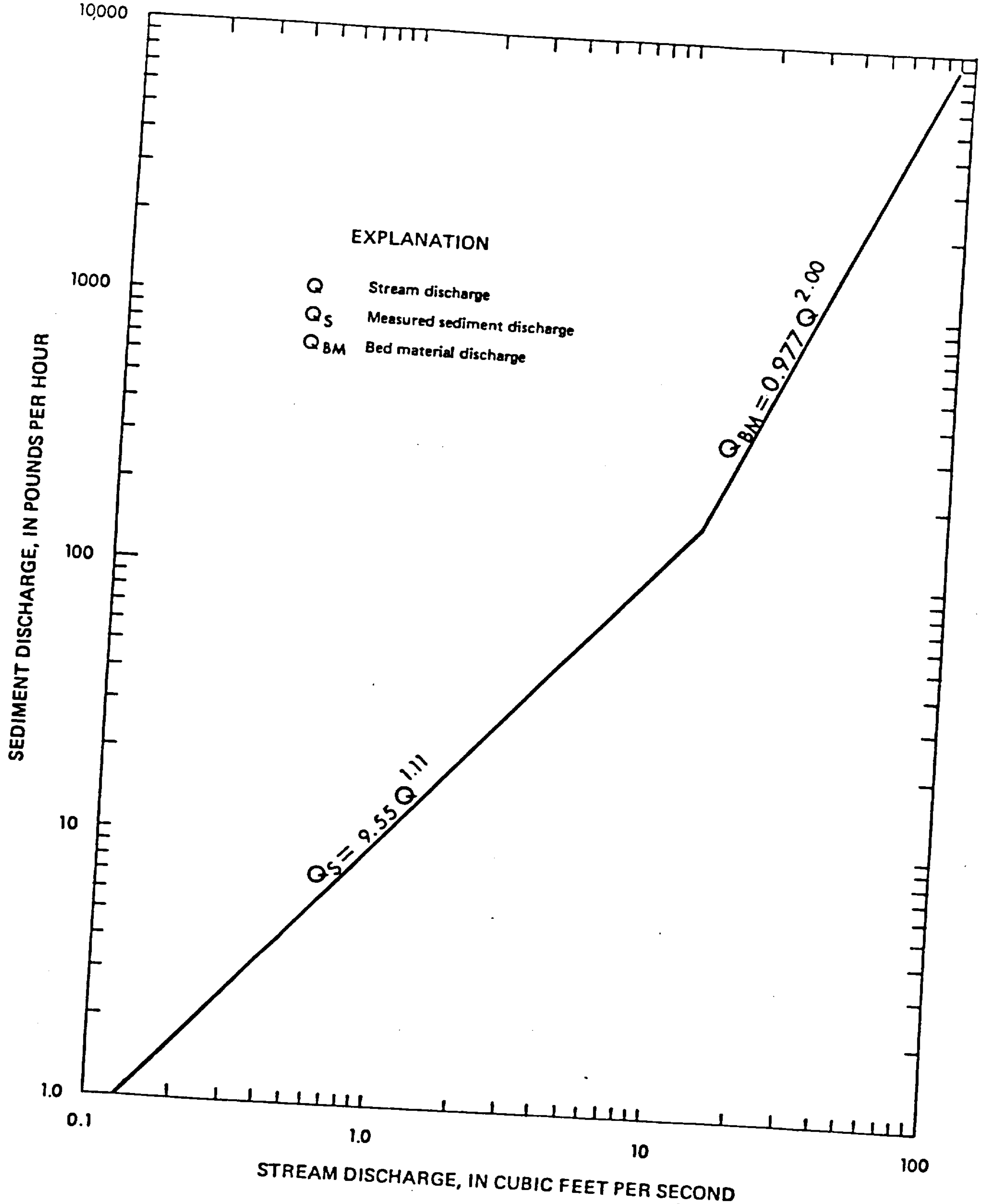

Figure 7.—Composite sediment transport curve.

Sediment Load Estimates

The regression line calculated from the measured sediment discharge was used to estimate sediment load for each day for which hourly stream discharge values were determined (table 2).

SUMMARY AND CONCLUSIONS

Stage-discharge and sediment-discharge to stream-discharge relations were developed by indirect methods and direct measurements and used to estimate daily sediment loads in North Ditch for the period March 13 to September 30, 1979. A barrier sand bar at the mouth of the ditch affected the stage-discharge relation. The maximum measured discharge and the mean daily discharge were 5.3 and 1.8 ft^3/s, respectively. The transport curve derived from measured sediment concentrations, used with hourly discharge values for days of known flow, gives an estimate of 5,100 lb for sediment transported through the ditch during the study period. Of that total, almost one-third was transported in the month of March. The maximum daily load was about 450 lb and the average daily load for the study period was about 25 lb. Sediment discharges corresponding to flood peak stream discharges were estimated using a bed material transport curve developed by indirect methods. Bed material discharge is estimated to be 250 lb/h at the peak discharge of the 2-year flood and 1,600 lb/h at the peak discharge of the 100-year flood.

Stream discharge and sediment loads estimated from measured sediment data are considered to be low. The amount of sediment not included in the estimate may be significant because 14 percent of the total rainfall occurred on days for which discharge could not be computed. During low-flow periods unmeasured sediment discharge is probably insignificant and the measured-sediment transport curve (the regression line) probably approximates total sediment discharge. During higher flow periods, the difference between estimates made from the measured-sediment data and the total sediment discharge will be greater because unmeasured discharge will be significant. At discharges higher than about 13 ft^3/s, the bed material transport curve calculated by Laursen's indirect method can be used to obtain estimates of sediment discharge. Because that method does not account for the silt and clay sized fraction, it will also yield a value which is less than the actual total sediment discharge.

Table 2.–Daily sediment load, mean daily discharge for selected days during the study period, and hourly peak discharge

Date	Sediment load (lb)	Discharge (ft^3/s) Mean daily	Peak
Mar. 25	56	0.3	–
Mar. 26	370	1.5	4.0
Mar. 27	220	0.9	–
Mar. 28	260	1.0	–
Mar. 29	360	1.4	4.1
Mar. 30	340	1.4	4.3
Mar. 31	12	0.1	–
Apr. 12	66	0.3	1.1
Apr. 13	27	0.1	–
May 11	230	1.0	2.3
June 6	13	0.1	–
June 7	42	0.2	1.1
June 8	21	0.1	–
June 14	22	0.1	–
June 15	84	0.4	1.6
June 29	450	1.8	3.7
June 30	290	1.2	–
July 4	99	0.4	2.1
July 12	51	0.2	–
July 13	140	0.6	2.1
Aug. 3	72	0.3	–
Aug. 4	170	0.7	–
Aug. 5	250	1.0	4.5
Aug. 6	97	0.4	–
Aug. 7	96	0.4	–
Aug. 11	140	0.6	1.9
Aug. 23	280	1.1	5.2
Aug. 24	30	0.2	–
Aug. 25	15	0.1	–
Aug. 29	210	0.9	3.4
Aug. 30	24	0.1	–
Sept. 1	71	0.3	–
Sept. 4	180	0.7	4.7
Sept. 5	130	0.5	–
Sept. 13	28	0.1	–
Sept. 14	100	0.4	5.3
Sept. 15	45	0.2	–
Sept. 16	20	0.1	–
Sept. 17	34	0.2	–
Total	5,100		

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